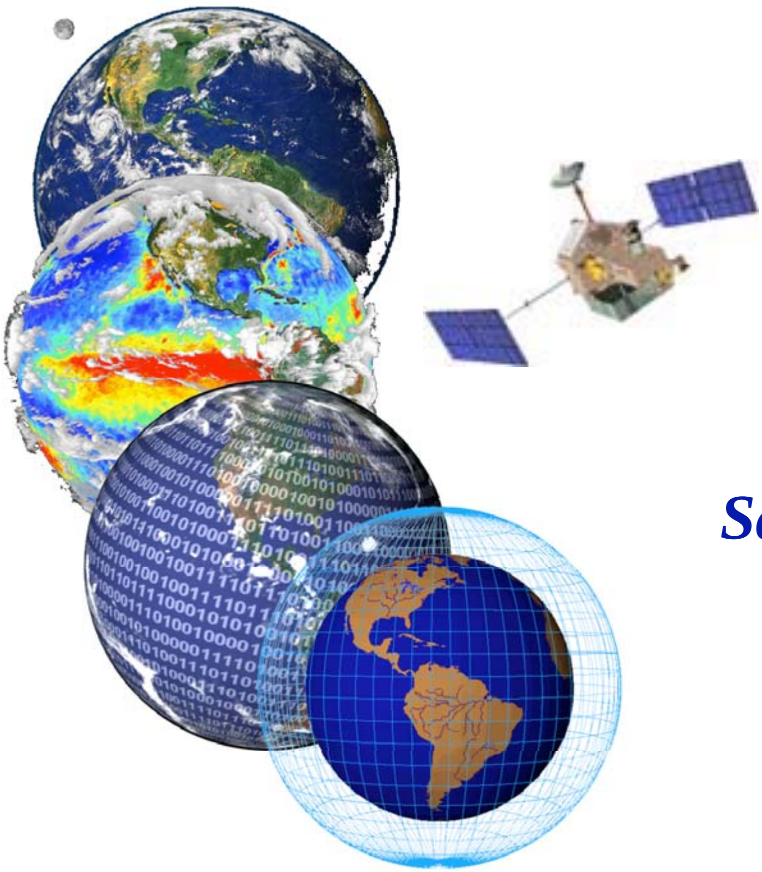
Using Remote Sensing for Continental-scale Water Budget Studies



Eric F. Wood

Princeton University

Global Water Cycle Session

Satellite Observations of theWater Cycle

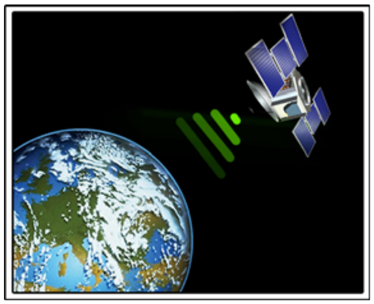
March 7-9, 2007

Beckman Center

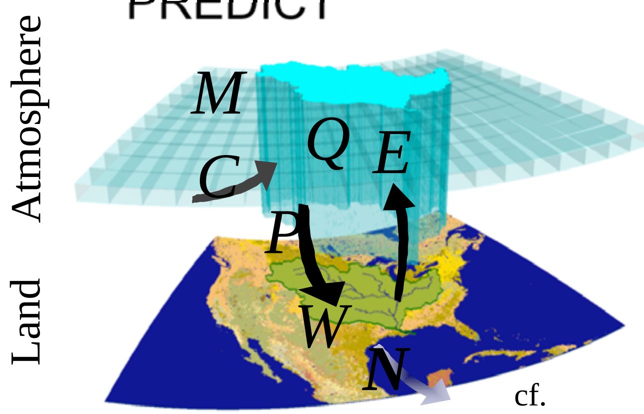
A VISION FOR THE PLANETARY WATER CYCLE

IMPLEMENT A NEW EPOCH OF WATER MANAGEMENT IN OUR LIFETIMES THAT IS FACILITATED BY OBSERVATIONS AND IMPROVED PREDICTION SYSTEMS.

OBSERVATIONS

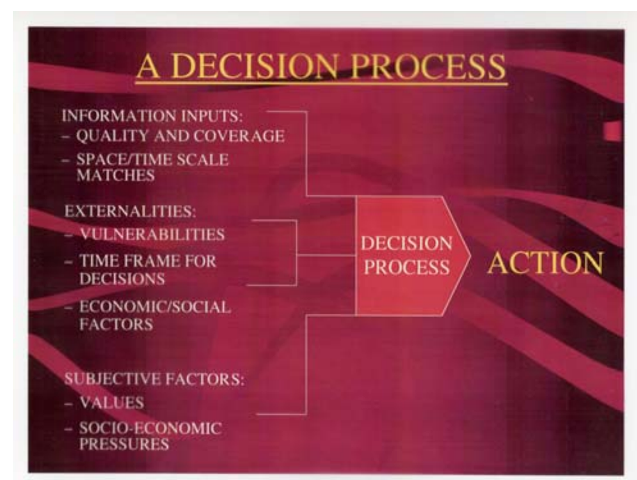


IMPROVED CAPABILITY TO ASSIMILATE AND PREDICT



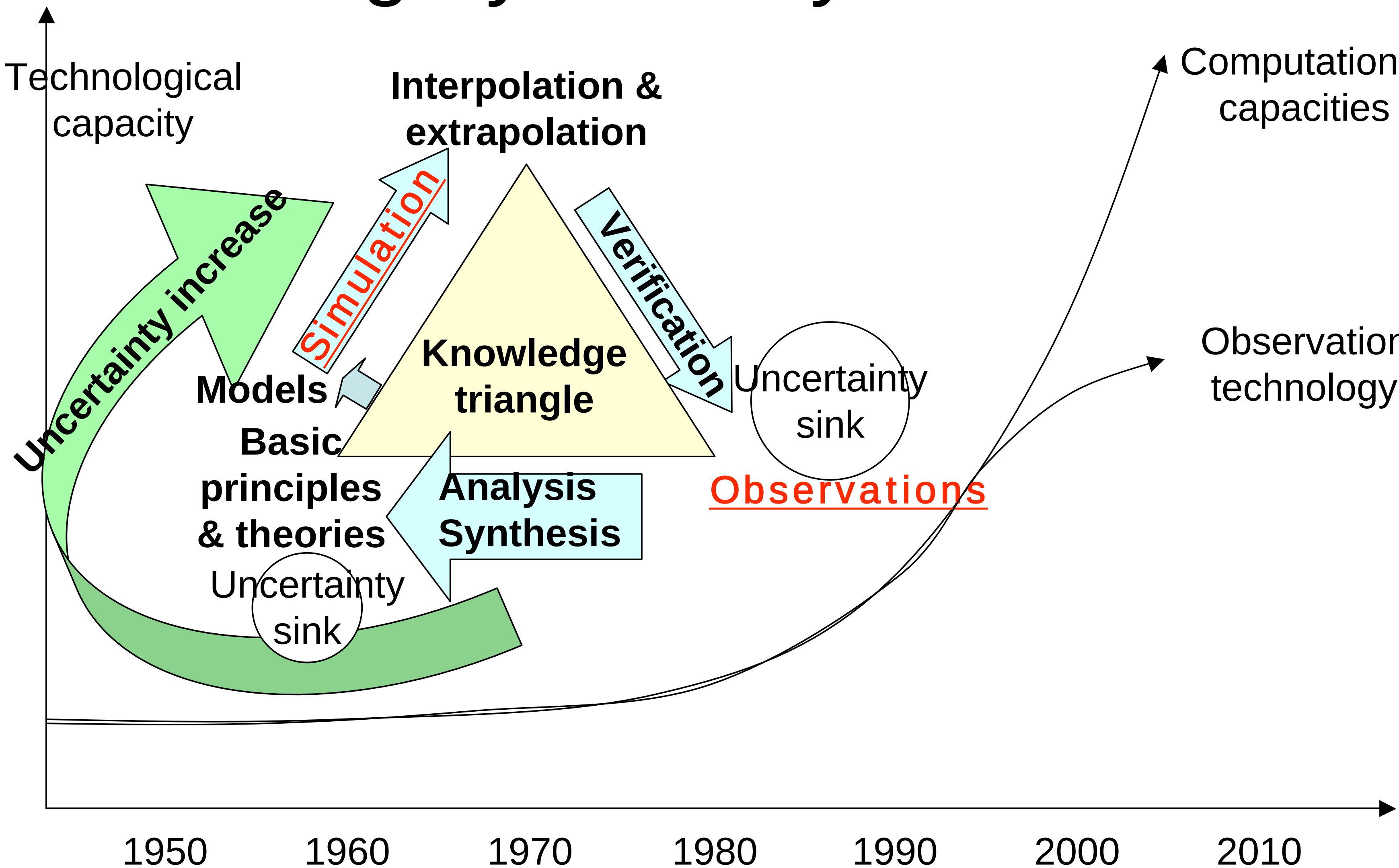
cf. Sorooshian

INTEGRATED DECISION SUPPORT SYSTEMS



(Courtesy R. Lawford)

Science increases gray zone.
Reduce gray zone by observations.

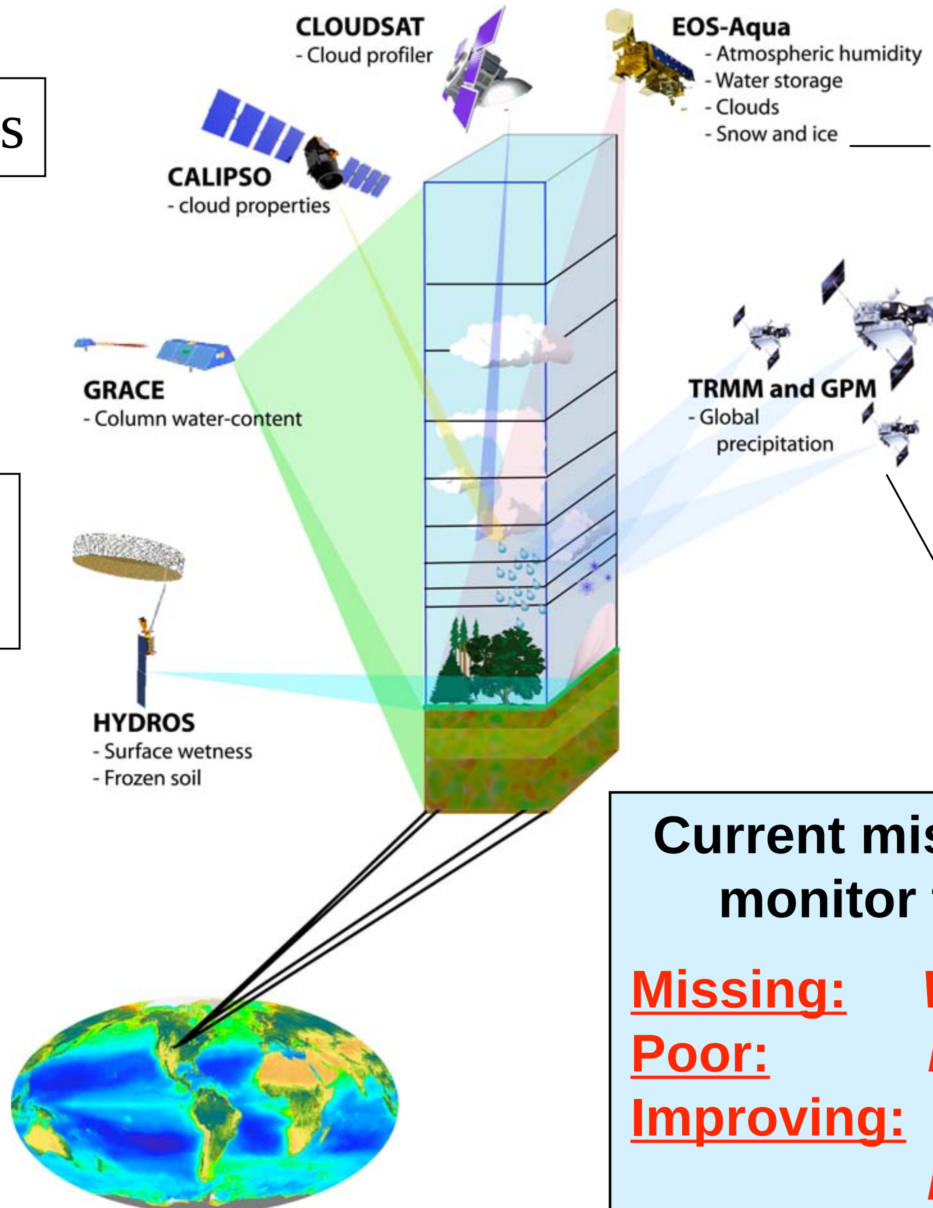


(Courtesy of K Takeuchi)

Advances in space observations for the Global Water Cycle

Clouds

Soil Moisture



Radiation (CERES)
Snow (AMSR-E)
Soil moisture (AMSR-E)
Vegetation (MODIS)
Soil moisture (AMSR)
Water vapor (AIRS)

Liquid precipitation

Current missions have a capacity to monitor the global water cycle.

Missing: *Wind*
Poor: *River/lake monitoring*
Improving: *Precipitation, Soil Moisture, Snow*

Land surface water budget (e.g., for a river basin):

$$\overline{P} - \overline{E} = Q_s + Q_g + d\overline{S} / dt$$

<u>For land surface models</u>

P → observed

E, Q_s, Q_g , dS/dt → parameterized

<u>For remote sensing retrievals (models)</u>

Q_s, Q_g → observed

E, P, dS/dt → parameterized

S_{gi} glaciers and ice sheets

Atmospheric water budget over a region (e.g. river basin):

$$\overline{E} - \overline{P} = \overline{\nabla \cdot \vec{Q}} + \frac{\partial \overline{(W + W_c)}}{\partial t}$$

where:

$\overline{E}, \overline{P} =$ are basin-averaged evapotranspiration and precipitation (as for surface water balance)

Q = vertically integrated water vapor transport

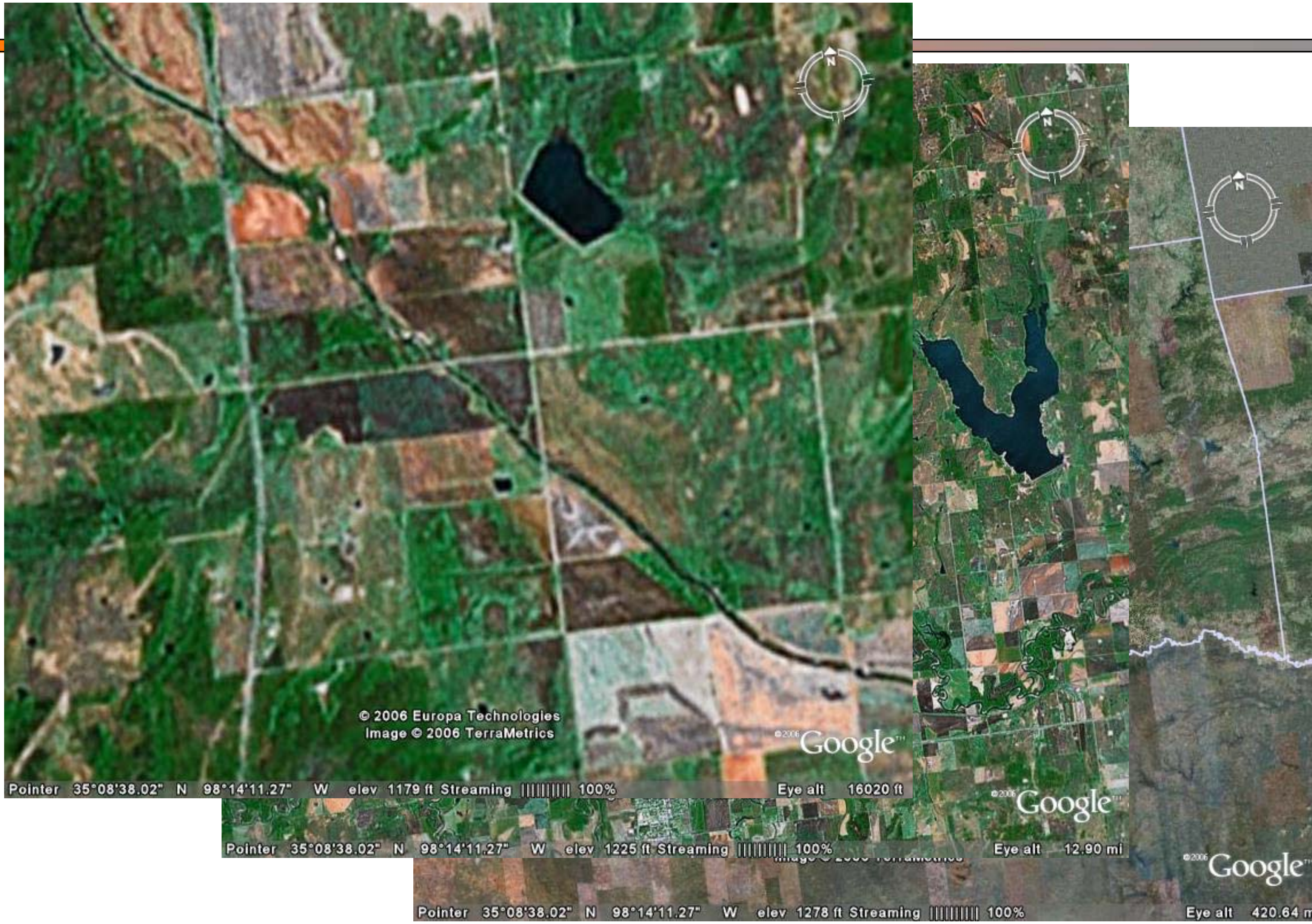
W = vertically integrated water vapor

W_c = vertically integrated cloud liquid water

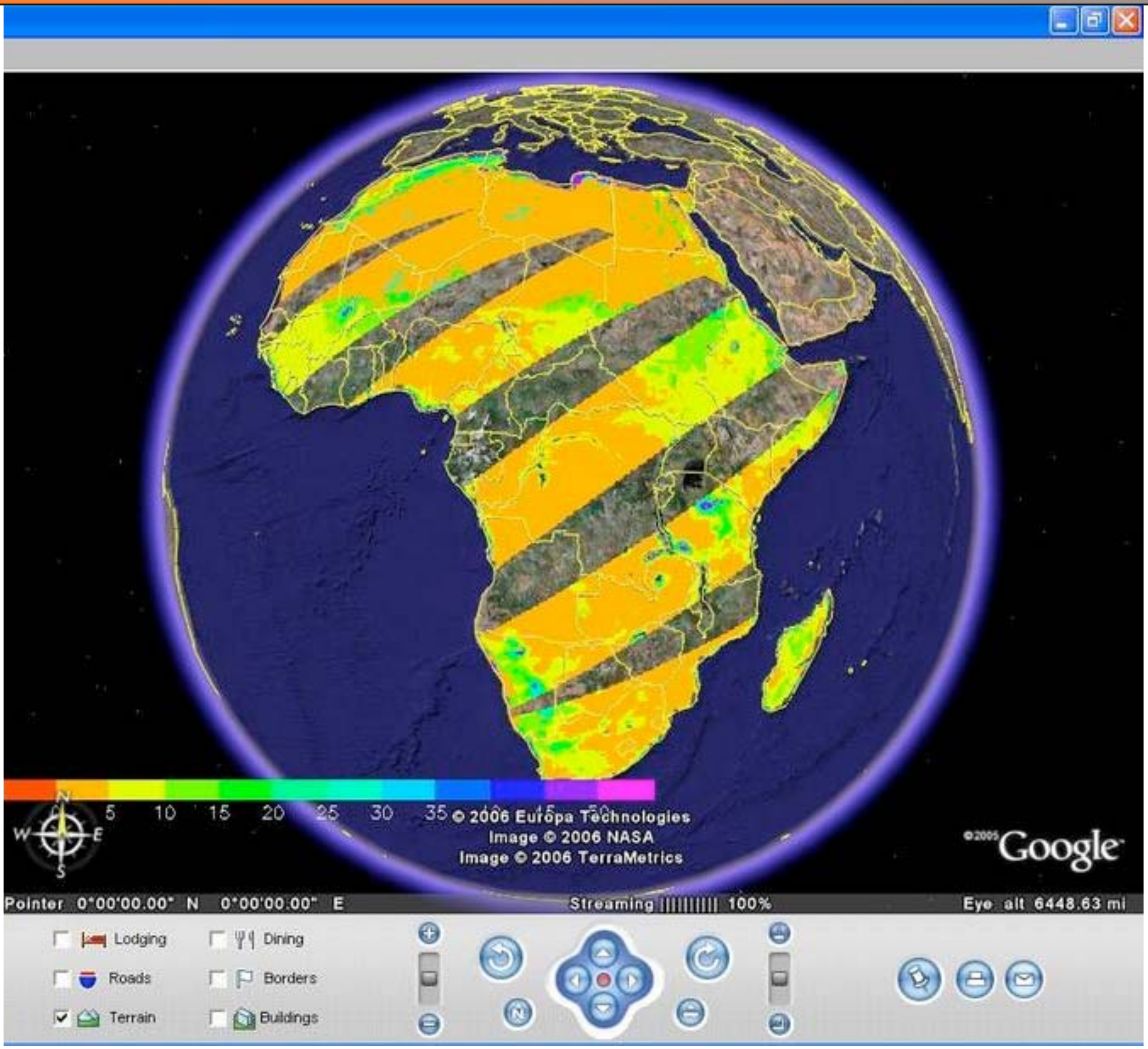
Challenges facing remote sensing

1. Issues of scale, and sub-pixel “contamination” and parameterizations.

Spatial Variability of Land Surface



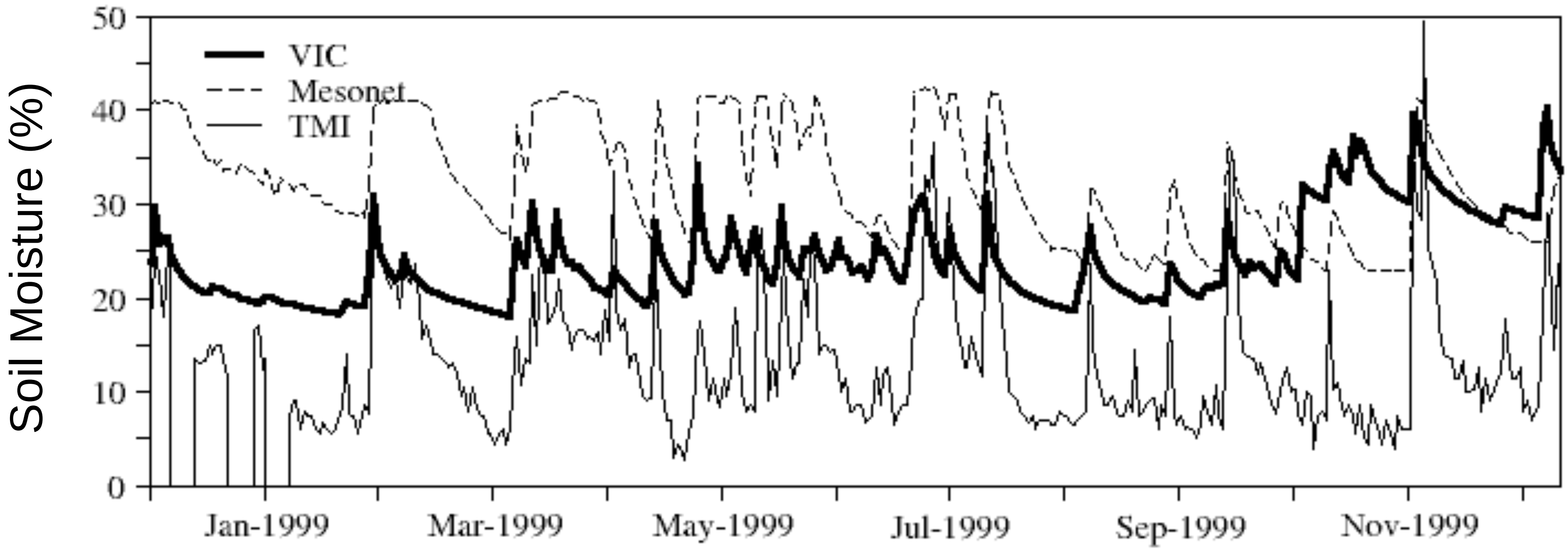
Soil Moisture from Space



Soil moisture retrievals and in-situ measurements

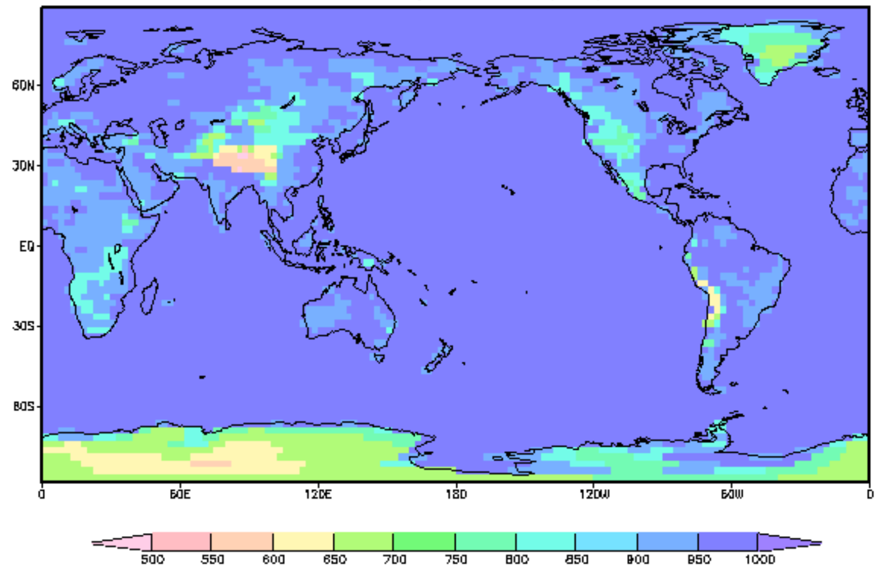
Time series from different sources, measured at different scales behave differently; yet they are correlated and show skill in data assimilation – how to evaluate them?

In-situ (points over the region); VIC (10 km); TMI (~35 km)

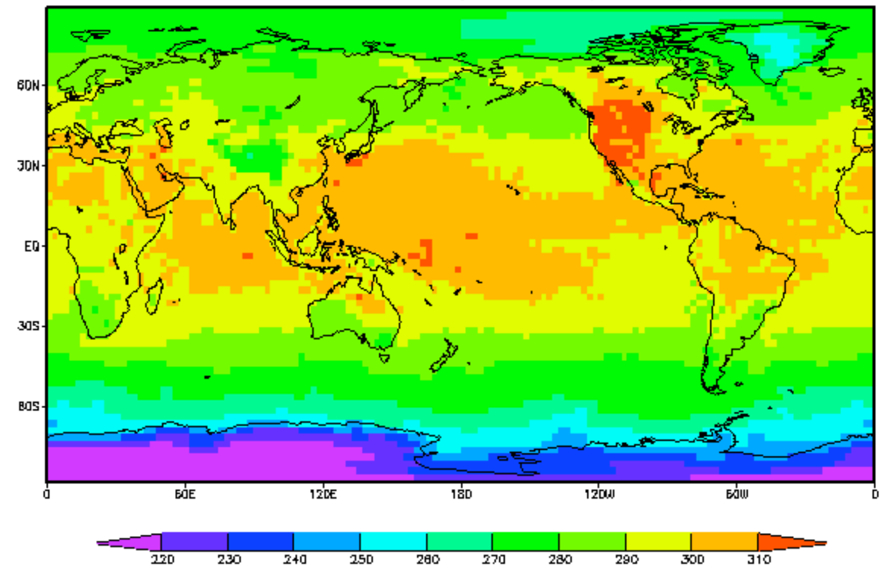


ISCCP 2003−08−15 21Z

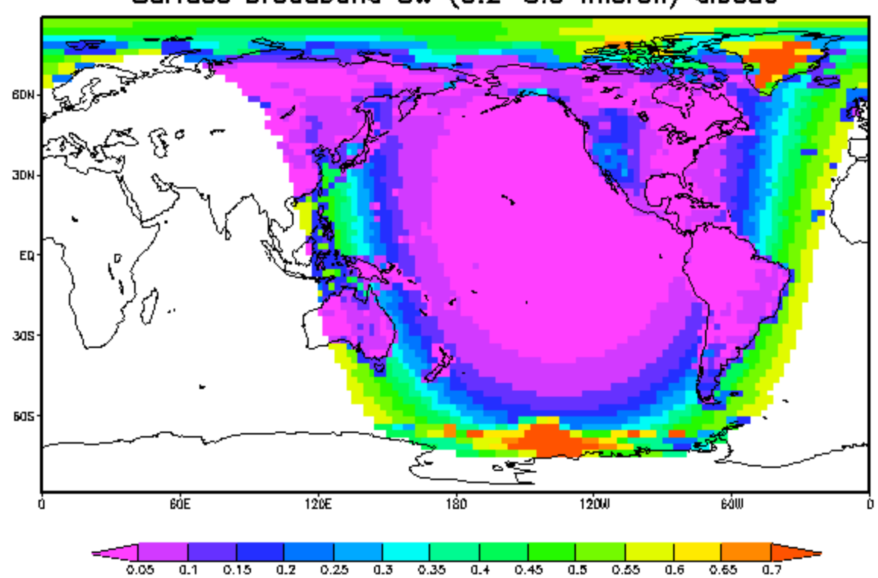
Surface pressure (mb)



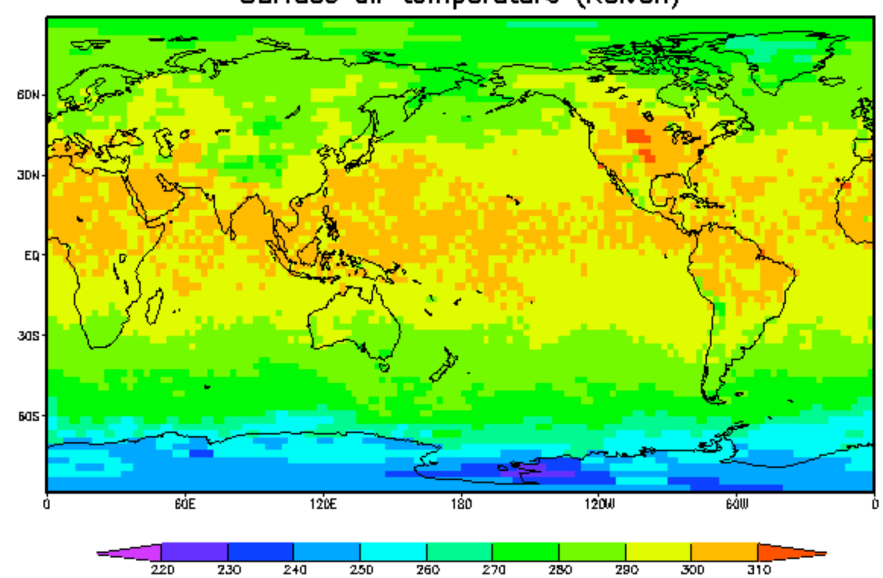
Surface skin temperature (Kelven)



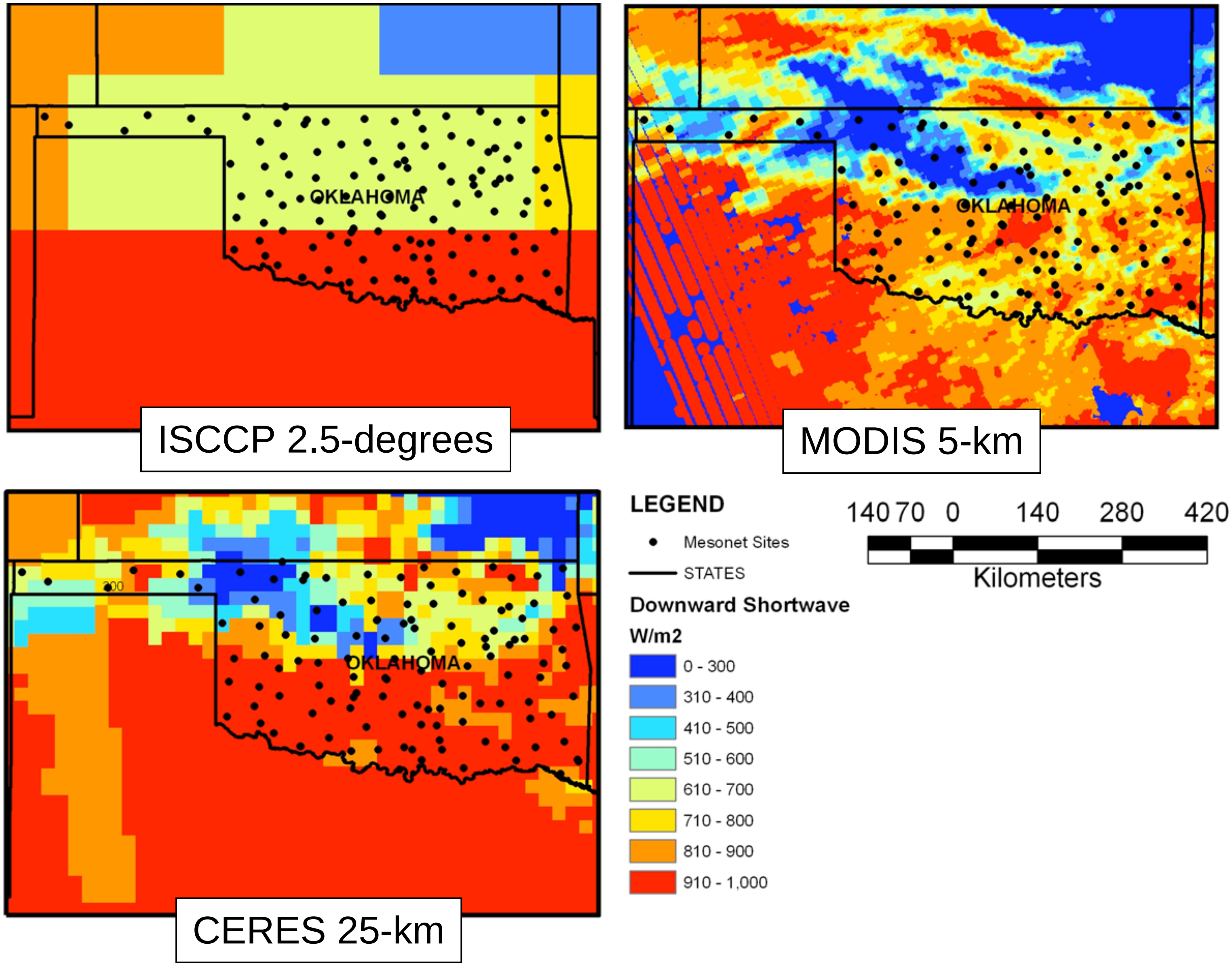
Surface broadband SW (0.2−5.0 micron) albedo



Surface air temperature (Kelven)



Surface insolation products for estimating ET (land heat fluxes)



Surface Energy Balance Model (SEBS) Model Approach

Basically SEBS calculates H using similarity theory, then constrains the estimates of H and λE based on wet (radiation limited) and dry (water limited) conditions.

$$u = \frac{u_*}{k}\left[\ln\left(\frac{z-d_0}{z_{0m}}\right) - \Psi_m\left(\frac{z-d_0}{L}\right) + \Psi_m\left(\frac{z_{0m}}{L}\right)\right]$$

$$L = -\frac{\rho C_p u_*^3 \theta_v}{kgH}$$

$$H = ku_*\rho C_p(\theta_0 - \theta_a)\left[\ln\left(\frac{z-d_0}{z_{0h}}\right) - \Psi_h\left(\frac{z-d_0}{L}\right) + \Psi_h\left(\frac{z_{0h}}{L}\right)\right]^{-1}$$

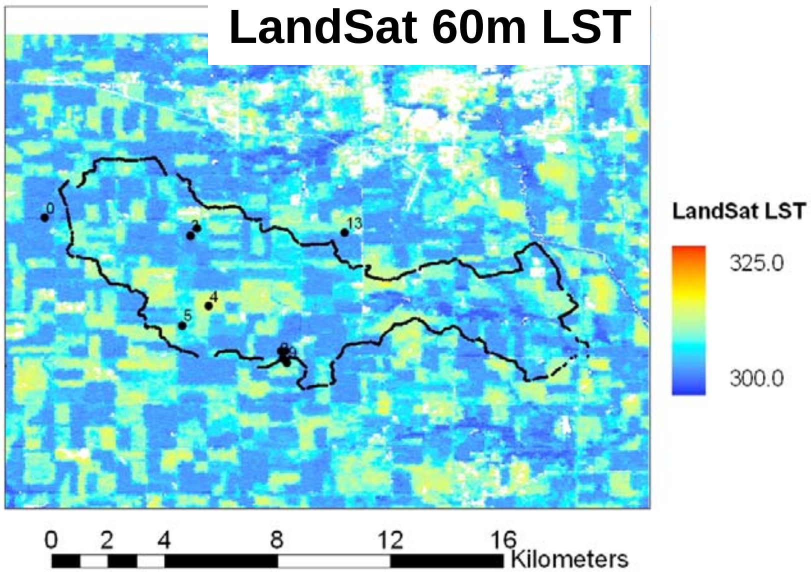
Stability functions

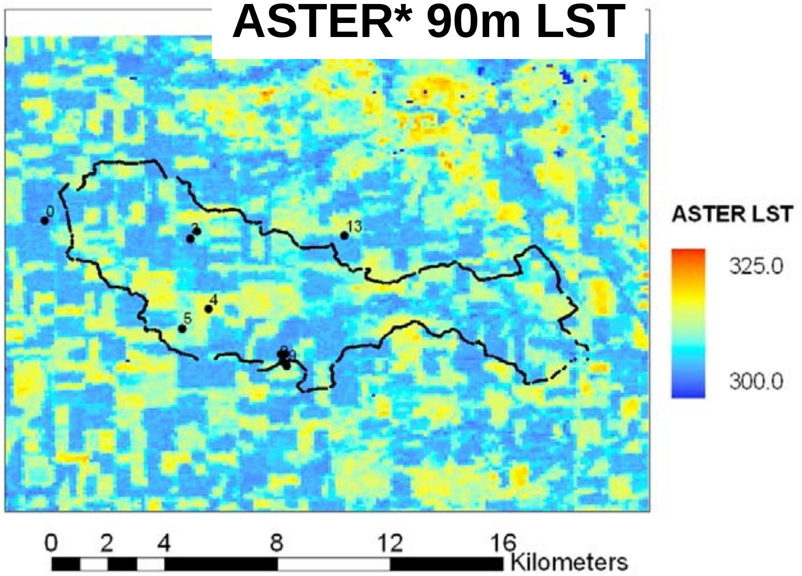
Potential temperature gradient

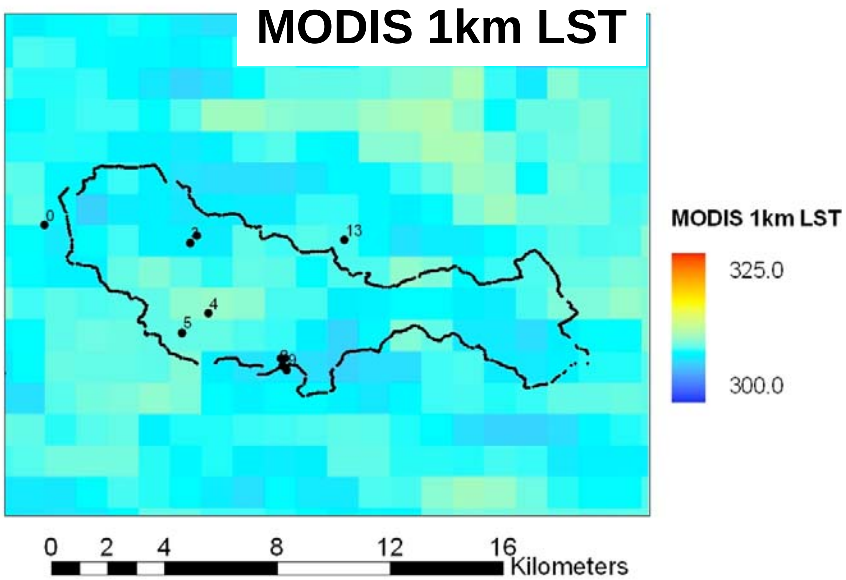
Wind, air temperature, humidity (aerodynamic roughness, thermal dynamic roughness)

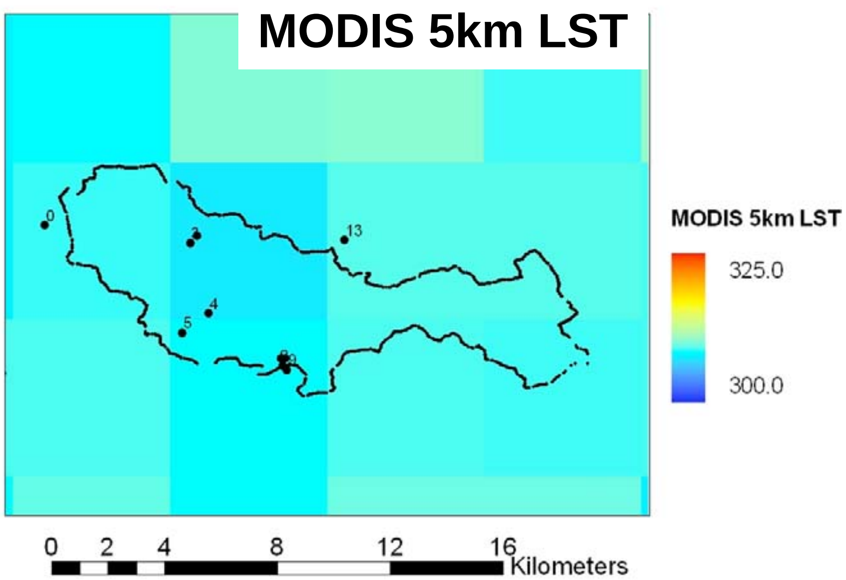
Various sub-modules for calculating needed components…

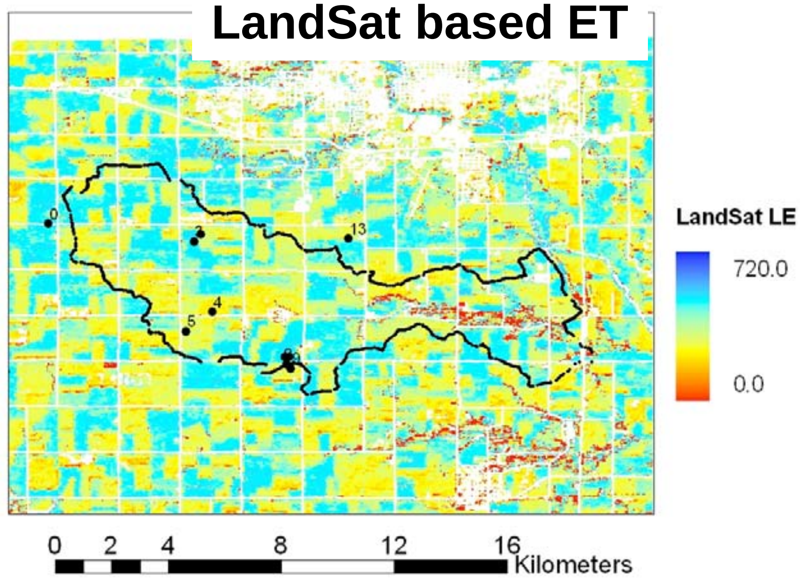
The issue of spatial scale

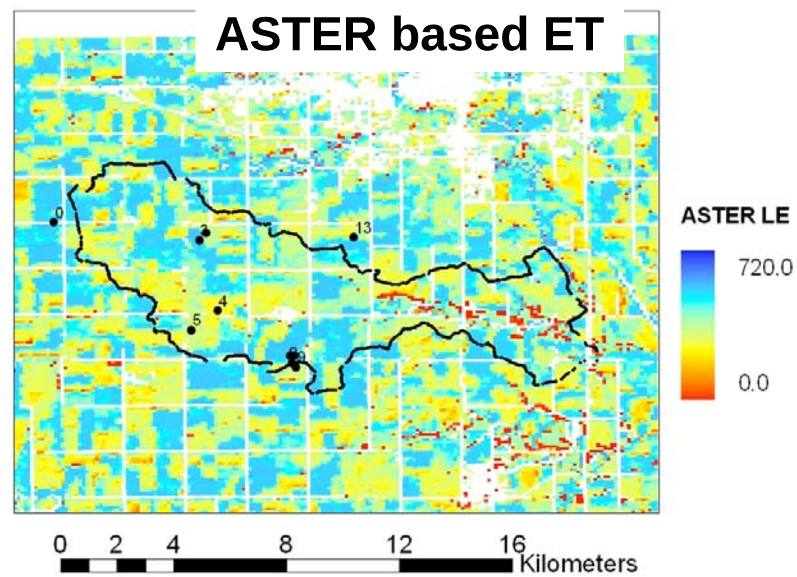


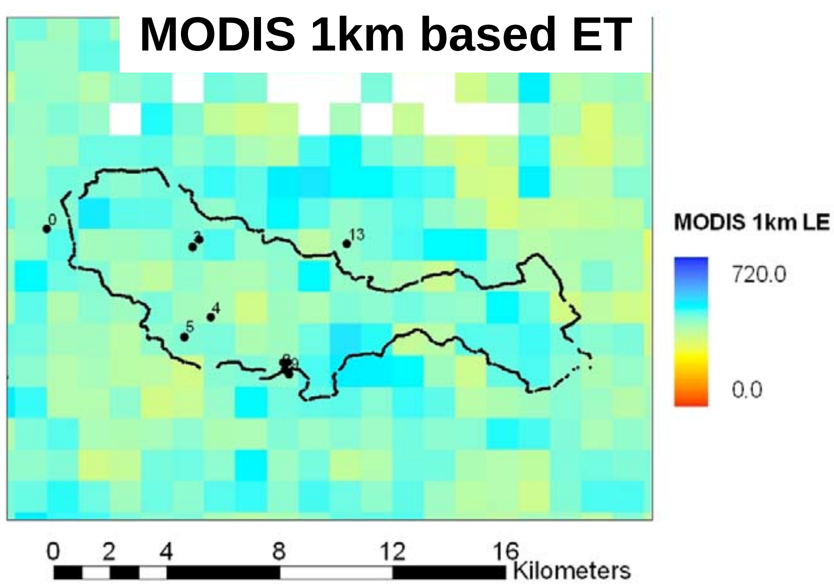


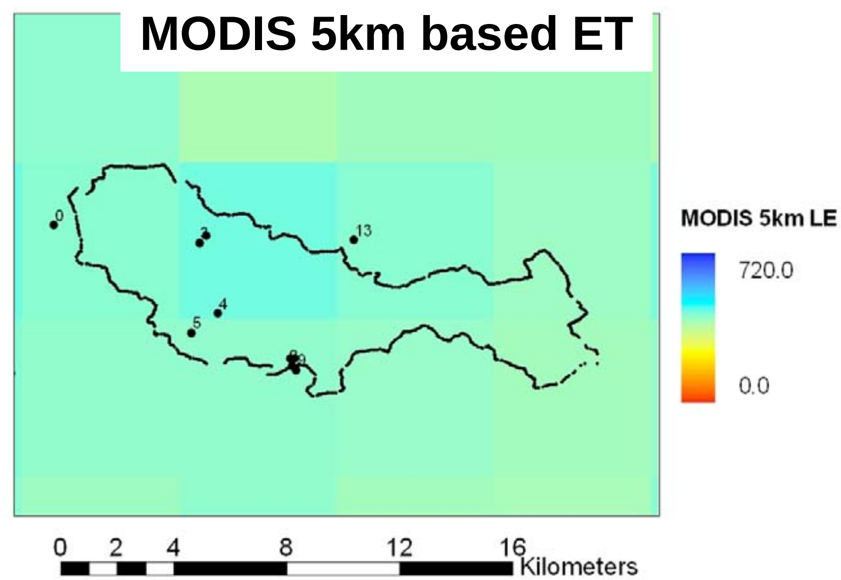




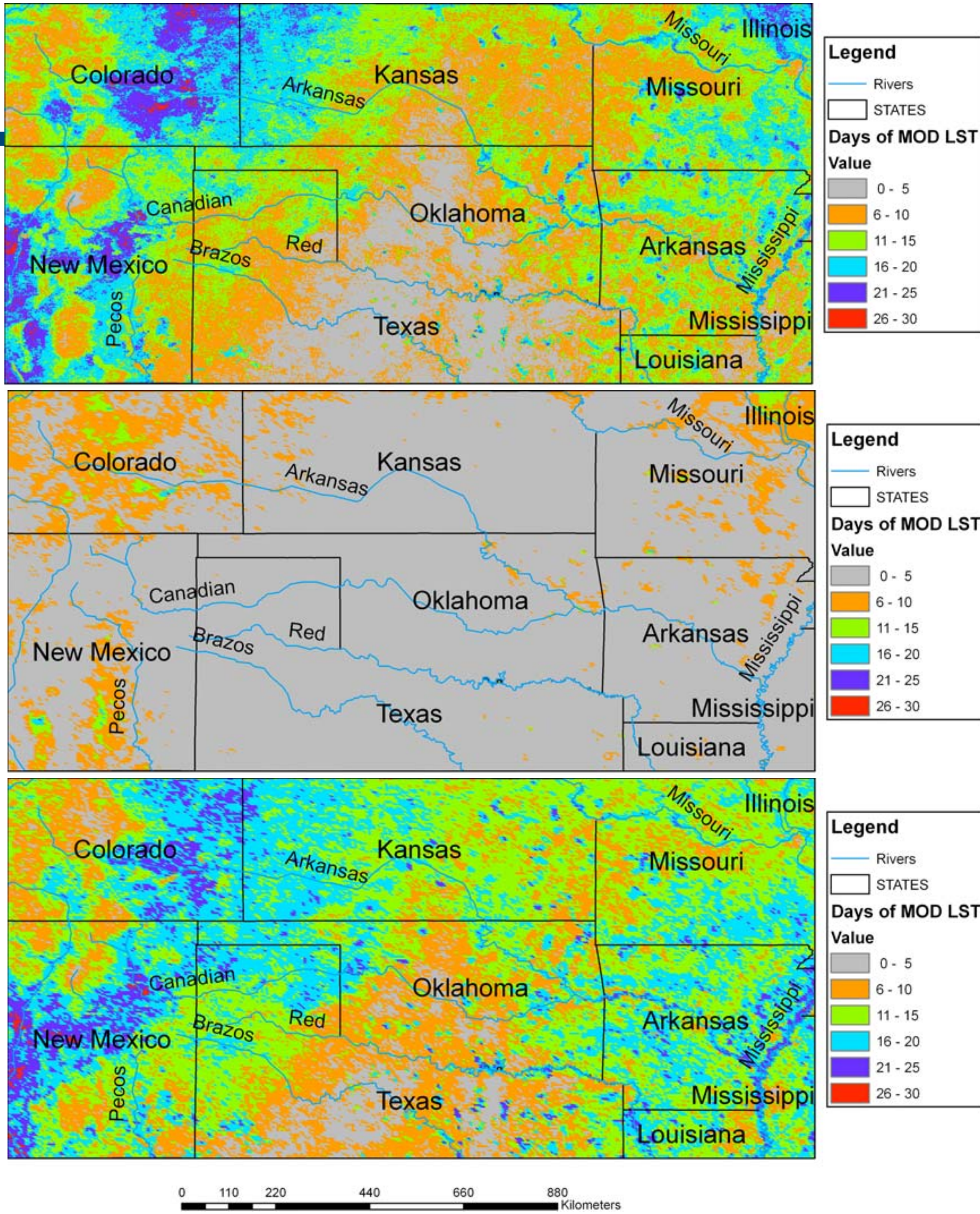

LandSat based ET
LandSat LE
720.0
0.0
0
2
4
5
13
0 2 4 8 12 16 Kilometers


ASTER based ET
ASTER LE
720.0
0.0
0
2
4
5
13
0 2 4 8 12 16 Kilometers


MODIS 1km based ET
MODIS 1km LE
720.0
0.0
0
2
4
5
13
0 2 4 8 12 16 Kilometers


MODIS 5km based ET
MODIS 5km LE
720.0
0.0
0
2
4
5
13
0 2 4 8 12 16 Kilometers

Available MODIS LST for August 2003



1-km MODIS Aqua (QC
Level 1&2: accuracy <=2K

5-km MODIS Aqua (QC
Level 1&2: accuracy <=2K

5-km MODIS Aqua (QC
Level 3: accuracy 2K - 3K

Most land surface models use a Penman-Monteith parameterization, which doesn’t use a surface temperature, but only needs 2-m air temperature and humidity, thereby making it impossible to have the spatial detail approaches like SEBS.

What parameterization should be used for continental-scale water budget studies i.e. ‘climate’ studies?

How to determine which is more accurate at large scales?

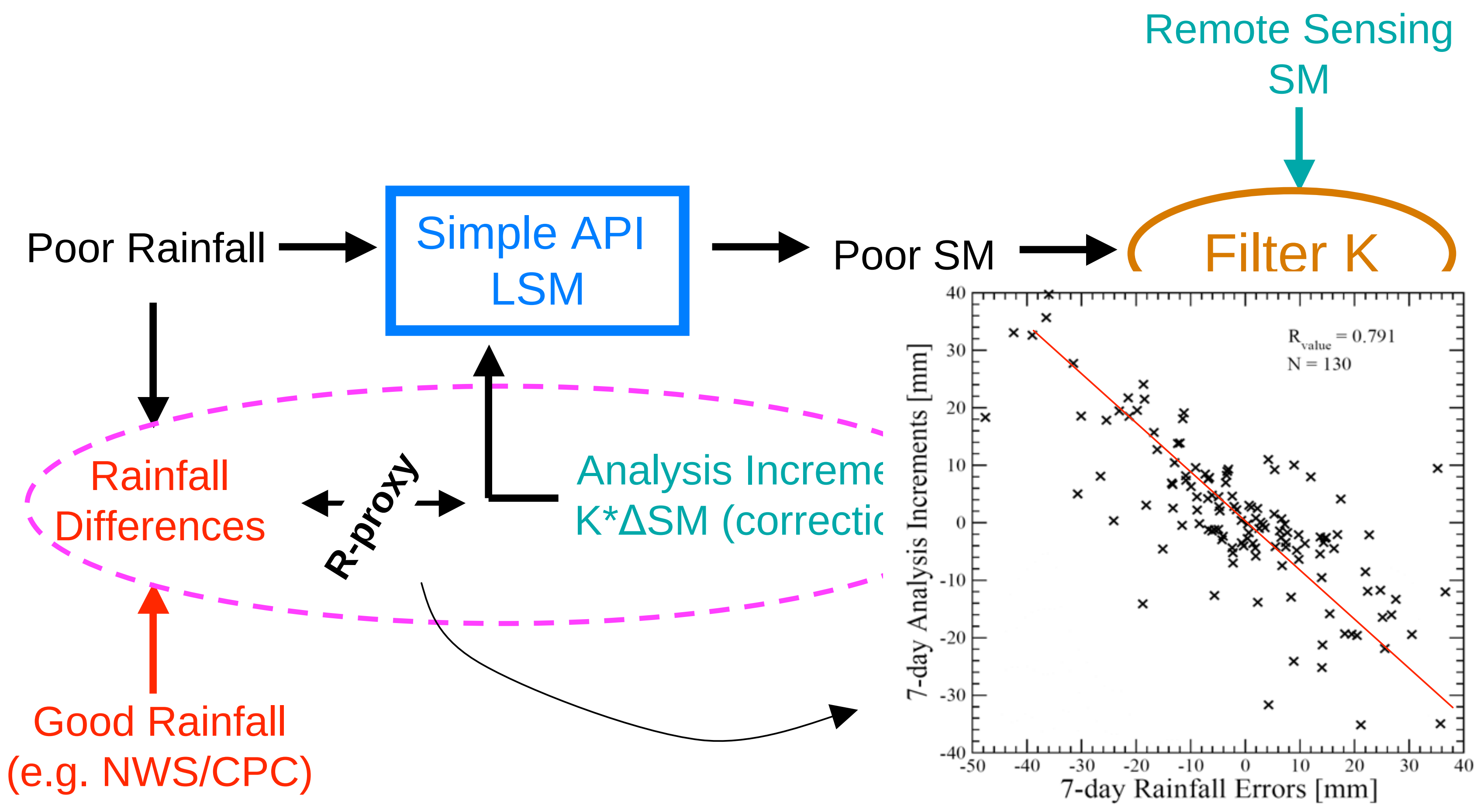
Challenges facing remote sensing

1. Issues of scale, and sub-pixel “contamination” and parameterizations

2. Remote sensing validation (and calibration) at large-scales: a new paradigm is needed.

Soil Moisture "Valuation" via Data Assimilation

Instead of comparing remotely-sensed soil moisture to ground measurements, look for **how much the soil moisture product can contribute when it is assimilated into a (simple) land surface model (LSM) driven by poor rainfall forcings (<u>after Crow, 2007</u>)**.

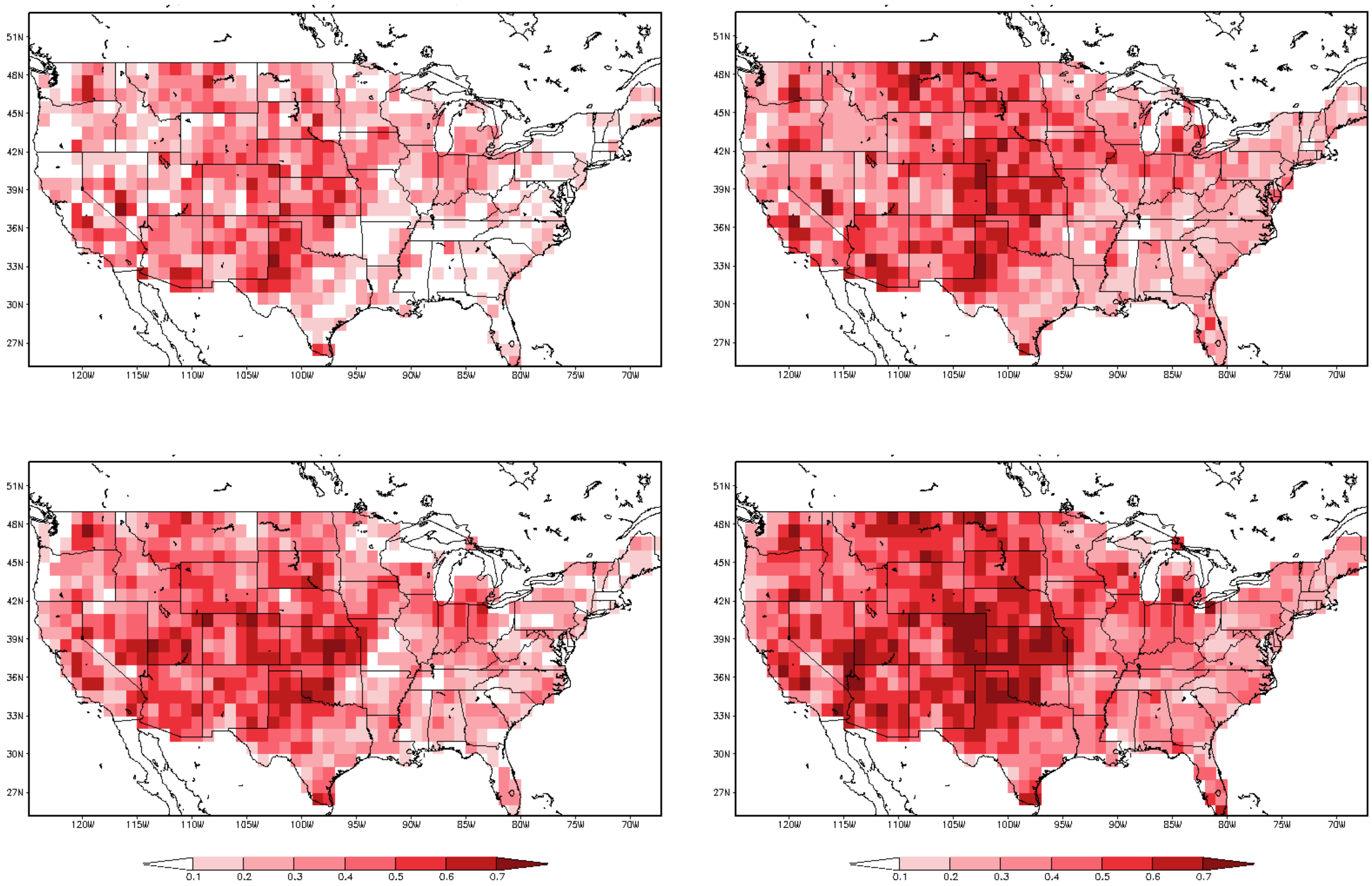


“R Proxies” using VIC and AIRS Ts for soil moisture retrievals

Before Calibration | After Calibration

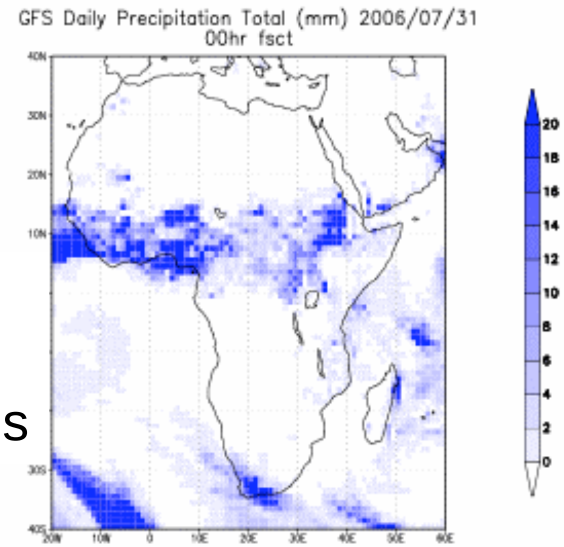
AIRS Ts Driven

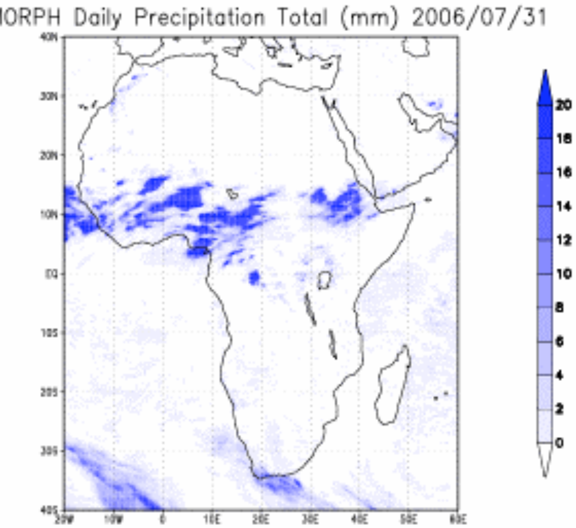
VIC Ts Driven



Real-time data availability for hydrology – the options

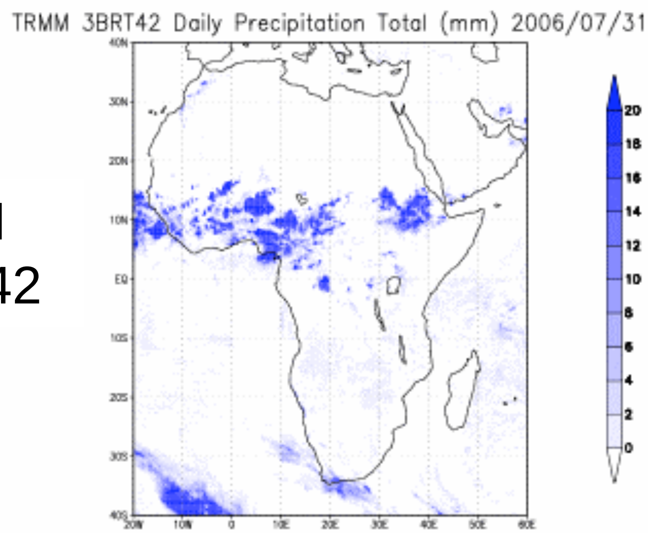
GFS
4-DDA
predictions

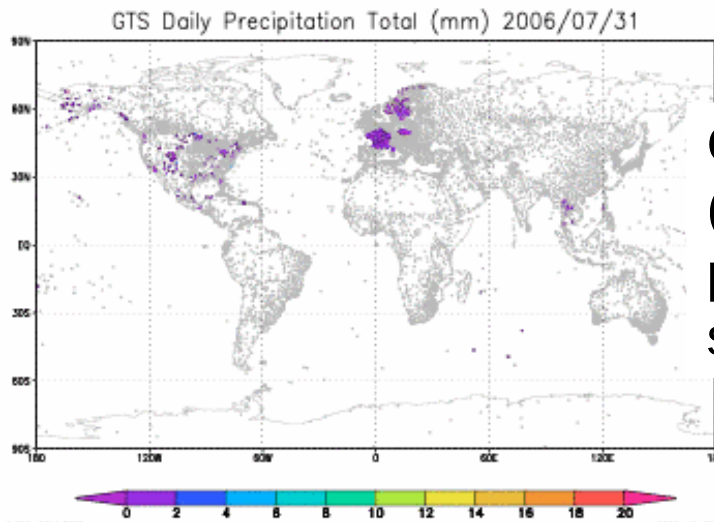




CMORPH

TRMM
3BRT42



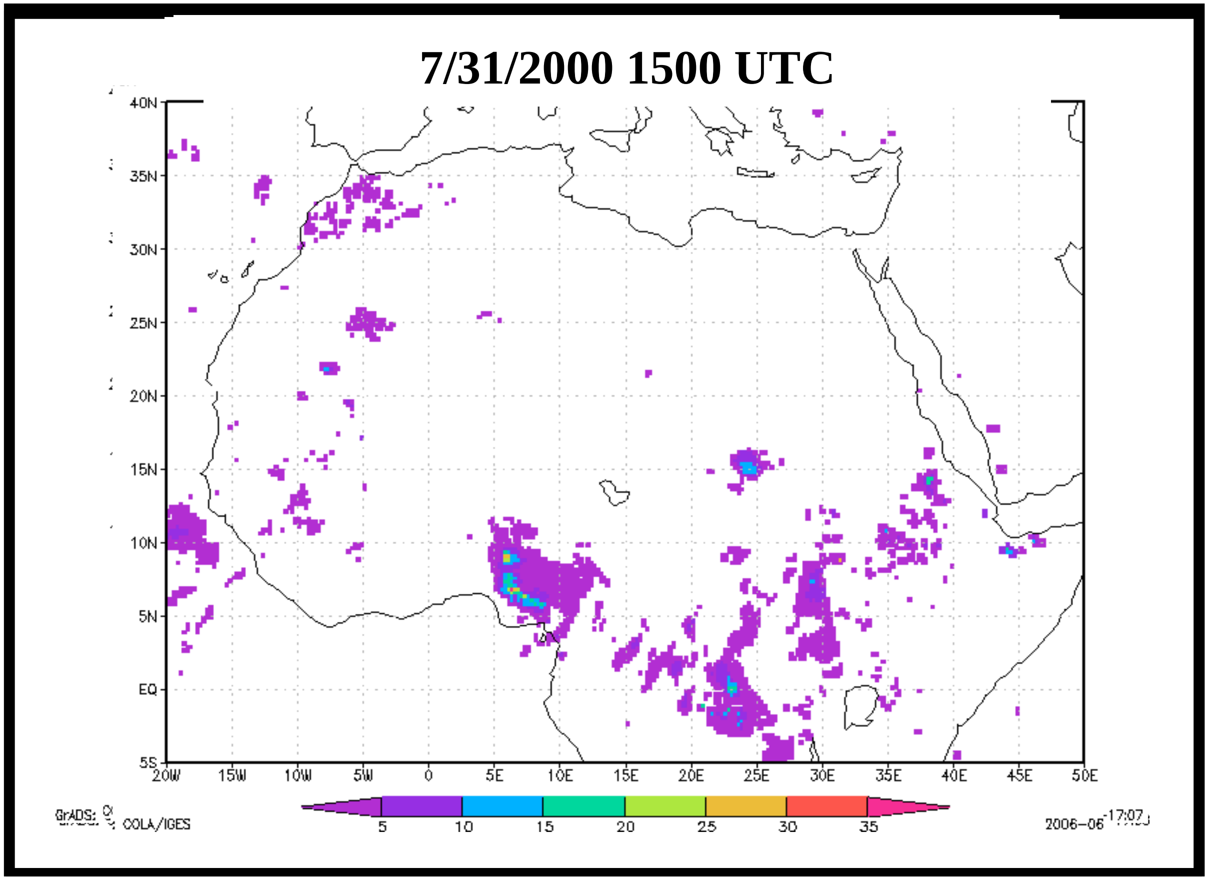


GTS
(in-situ) daily
precipitation
stations

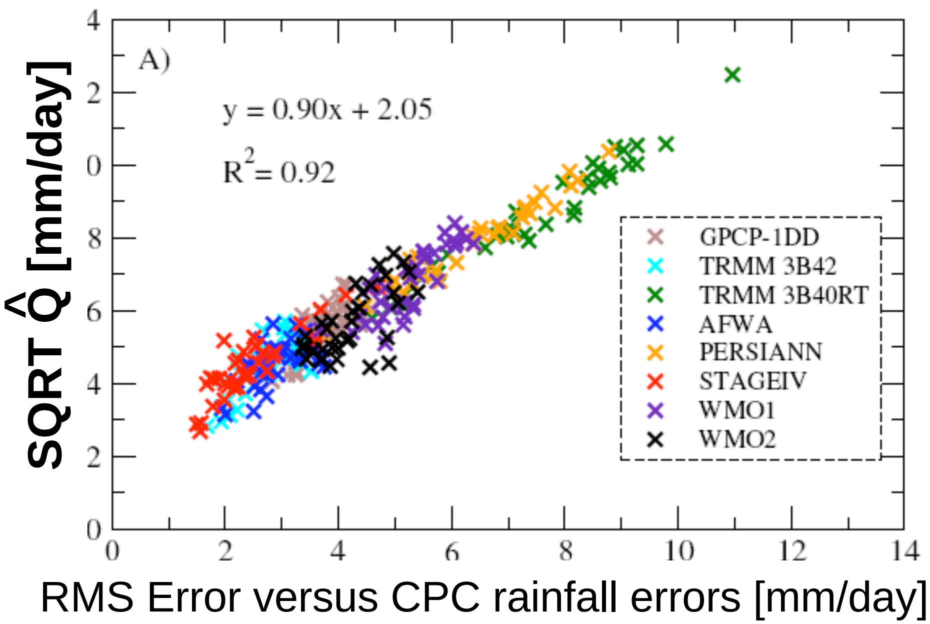
Data availability for hydrology – satellite precipitation

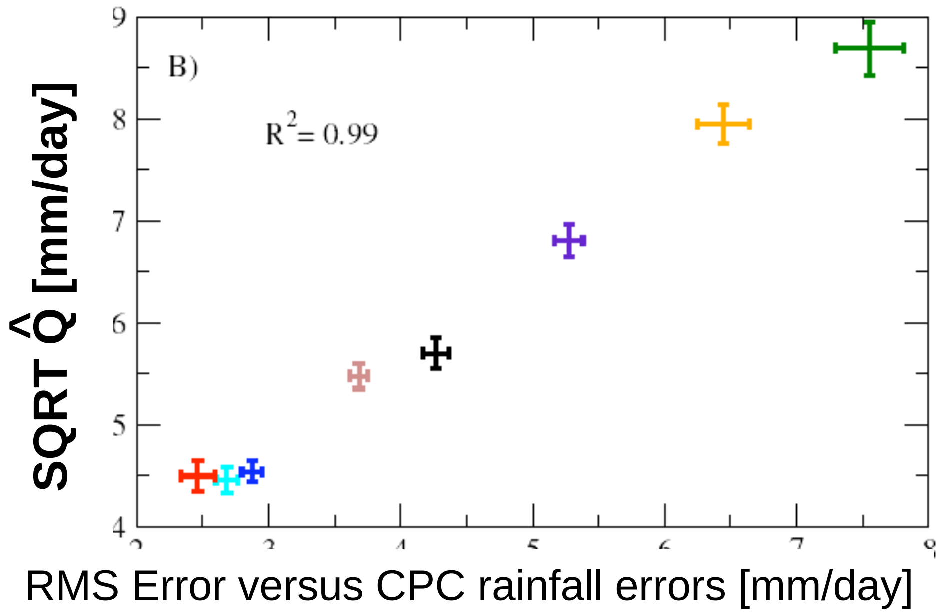
TRMM 3B42 merged high quality infrared precipitation product- 3hrly 0.25 x 0.25 degree gridded estimates of global precipitation [mm/hr] (instantaneous precipitation rate at the nominal observation time)

algorithm available at: http://trmm.gsfc.nasa.gov/3b42.html



Using adaptive filtering to estimate errors from <u>satellite-retrieved precipitation</u> (from Crow and Bolton, 2007)





Estimated forecast error versus CPC for a number of 1-degree boxes in the SGP (US region) (July 1, 2002 to Dec 31, 2005)

Estimated forecast error versus CPC spatially averaged for all boxes and retrievals.

Challenges facing remote sensing

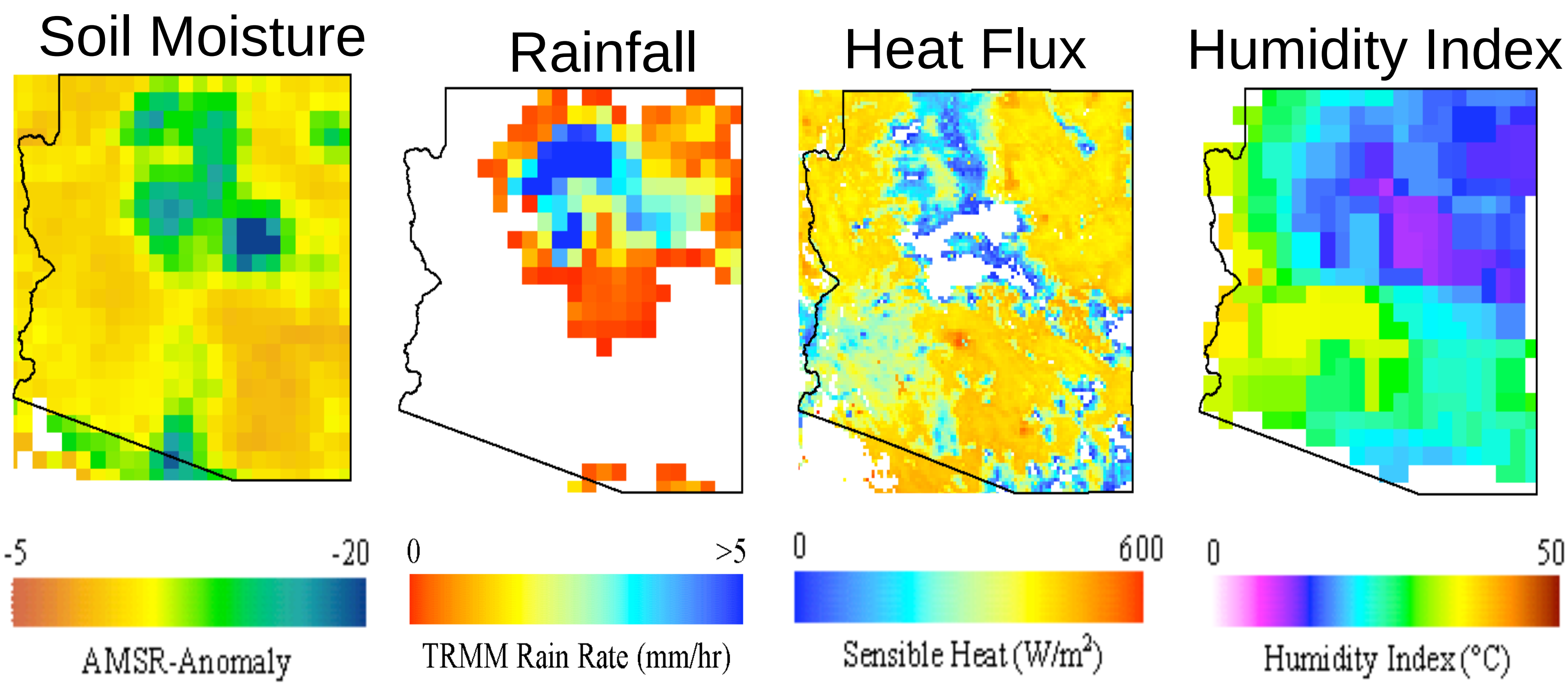
1. Issues of scale, and sub-pixel “contamination” and parameterizations

2. Remote sensing validation (and calibration) at large-scales: a new paradigm is needed.

3. Understanding consistency among retrieved data fields – new approaches for data assimilation. Lots of activity happening.

Key issues with remote sensing of water cycle:

- How reliable are independent observations?
- Can we model/monitor water & energy fluxes through land-atmosphere-ocean systems (recycling)?
- Can we monitor/predict drought/flood risk?
- How to link observations with models – scale issues?
- How to harness remote observations to make system level predictions/responses



(From McCabe and Wood, RSE, 2007)

Summary.

Through modeling and remote sensing it is possible today to carry out water budget studies – perhaps even using only remote sensing. But, we still don't know how good these estimates are, or how good we need them to be.

A final workshop proposal: as a community we should assess the current state of the water system, and perhaps a retrospective (~1990) assessment. Thiscould be a GEWEX activity, perhaps with the UN's Program on Sustainable Development or the World-wide Water Assessment Programme.